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SYSTEM PLANNING CORPORATION

AERONAUTICAL STRUCTURES TECHNOLOGY STUDY

ANNOTATED BRIEFING REPORT

SPC 850

September 1982

R. B. Baird
J. C. Fish

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ABSTRACT

This document reports on quantitative and qualitative measures of benefit that were developed for use in determining the significance of aeronautical structures technology programs. The measures of benefit were developed for four categories: structures/materials, manufacturing, ownership, and operational, which represent the total life of an aircraft structure from initial design to final operation and ownership. The study also reports on two conceptual weapon systems, the Advanced Tactical Fighter and the Advanced Concepts Flight Vehicle; their operational and technical characteristics were determined for use in the subsequent analysis. The document includes recommendations on new structures technology initiatives that should be pursued for the conceptual weapon systems.

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CONTENTS

EXECUTIVE SUMMARY

A. PURPOSE

The purpose of this study, conducted by System Planning Corporation (SPC) for the Defense Advanced Research Projects Agency (DARPA) and the Advanced Development Program Branch of the Air Force's Flight Dynamics Laboratory, was to develop quantitative and qualitative measures of benefit (MOBs) for use in determining the significance of aeronautical structures technology programs. This report documents the results of SPC's work.

B. BACKGROUND AND OBJECTIVE

During the past 22 years, advanced aeronautical structures technology has been applied to operational fighter aircraft in a very selective, restrictive manner. The F-4 aircraft, which has a semi-monocoque structure, became operational around 1960. The F-15 aircraft, which was introduced into the fleet in 1974, utilizes the same structural concept except for the vertical stabilizer and the horizontal stabilator. The F-16 aircraft structure also is semi-monocoque, except for the horizontal stabilator. It was deployed in 1979. All of these aircraft are still operational.

A disturbing trend in structural efficiency is evident in the increase in the structural weight fraction, e.g.:

$$\frac{\text{Structure Weight}}{\text{Gross Take-Off Weight}} \quad ;$$

this value has increased from 0.36 for the F-4 to 0.41 and 0.45 for the F-15 and F-16 aircraft, respectively. Because of this trend and on the basis of the premise that a satisfactory return on investment (ROI) has not been made in aeronautical structures due to inadequate investment,[1] it was concluded by DARPA and the Department of the Air Force that a new look at structures technology is needed. Therefore, SPC was tasked to develop quantitative and qualitative parameters or MOBs that can be utilized to judge the significance of structures technology programs. These MOBs can be used to: (1) assess structural requirements of future weapon systems, (2) determine the adequacy of current structures technology programs, (3) determine deficiencies and identify new structures initiatives, and (4) assist in determining the ROI from the new initiatives.

---

[1]The Air Force has invested approximately \$60-\$70 million in the last 10 years in the advanced metal structures area. In view of the fact that one F-16 RDT&E aircraft costs approximately \$115 million, the investment in advanced structures appears to be minimal.

C. APPROACH AND SCOPE

The study was accomplished in five phases, as summarized below.

1. Literature Search

The SPC study team conducted a literature search at the Defense Technical Information Center (DTIC) in Alexandria, Virginia, and the Aerospace Structures Information and Analysis Center (ASIAC) at Wright-Patterson Air Force Base, Ohio. Both of these facilities have abundant technical data on aeronautical structures, but the ASIAC facility was more useful for purposes of this study. An extensive screening of more than 2,000 abstracts in the ASIAC card file producted 137 technical reports of interest. The study team reviewed these reports and selected 28 of them for additional detailed analysis. A list of these reports is provided at the end of this document.

2. Future Air Force Weapon Systems Definition

Two new weapons systems that would be operational in 1995 were defined for purposes of the study: The Advanced Tactical Fighter would have greatly improved performance when compared to current fighter aircraft. The Advanced Concepts Flight Vehicle is a fully reusable, launch-on-demand, lifting reentry space system concept. SPC determined operational and technical characteristics for each of these weapon systems for use in subsequent technology program analysis.

3. Structural Measures of Benefit

Thirty-six MOBs were developed during the study to assist in the development and assessment of aeronautical structures technology programs. These MOBs were developed for four categories: structures/materials, manufacturing, ownership, and operational. These categories represent the total life of the structure from initial design to final operation and ownership.

4. Methodology for Measures of Benefit Utilization

The fourth phase of the study was devoted to developing methodologies by which the MOBs can be used to judge the significance of aeronautical structures technology programs. One method employs a benefit/interest matrix that illustrates to what degree technical/management experts are familiar with the MOBs of interest. The other methodology is used to determine what MOB level is required for the new weapon systems (defined in the second phase of the study); this enables a comparison between the required MOB level for the new weapon systems and the MOB level that is expected to be achieved through the current structures technology program. From this comparison, deficiencies in the current program can be determined.

5. New Structures Initiatives

The final phase of the study utilized the results from the methodologies to define new structures technology programs that should be pursued for the Advanced Tactical Fighter and the Advanced Concepts Flight Vehicle.

D. RESULTS

The 36 MOBs that SPC developed in this study cover a wide range of interest, which allows them to be used to tailor discussions with technical/management experts to enhance communications and understanding of structures technology programs.

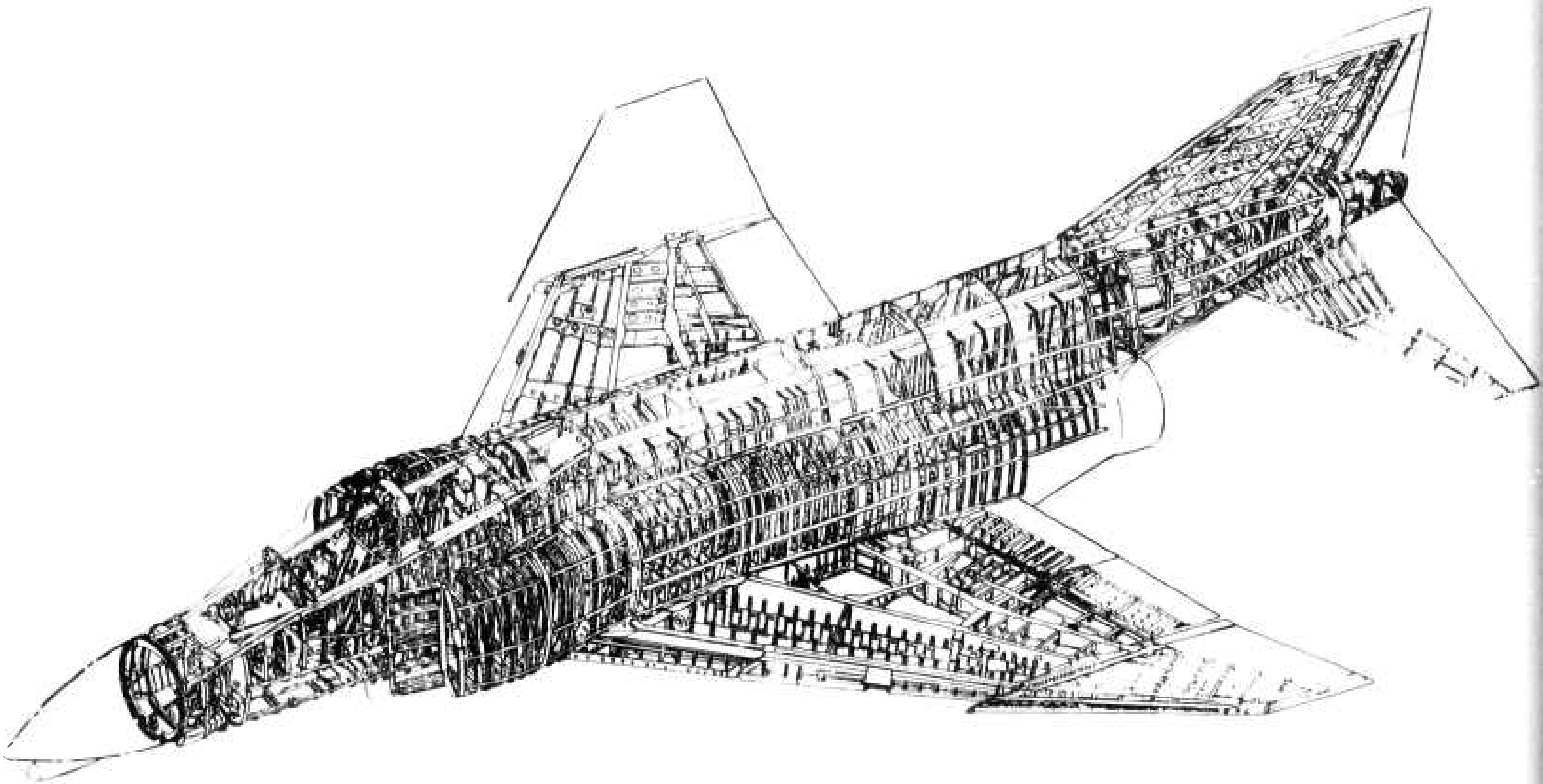
The MOBs have significant potential for use in (1) assessing the significance of aeronautical structures technology programs, (2) assessing the structural requirements of future weapon systems, (3) determining the adequacy of current structures technology programs, and (4) determining deficiencies and new structures technology initiatives.

ANNOTATED BRIEFING

AERONAUTICAL STRUCTURES TECHNOLOGY STUDY

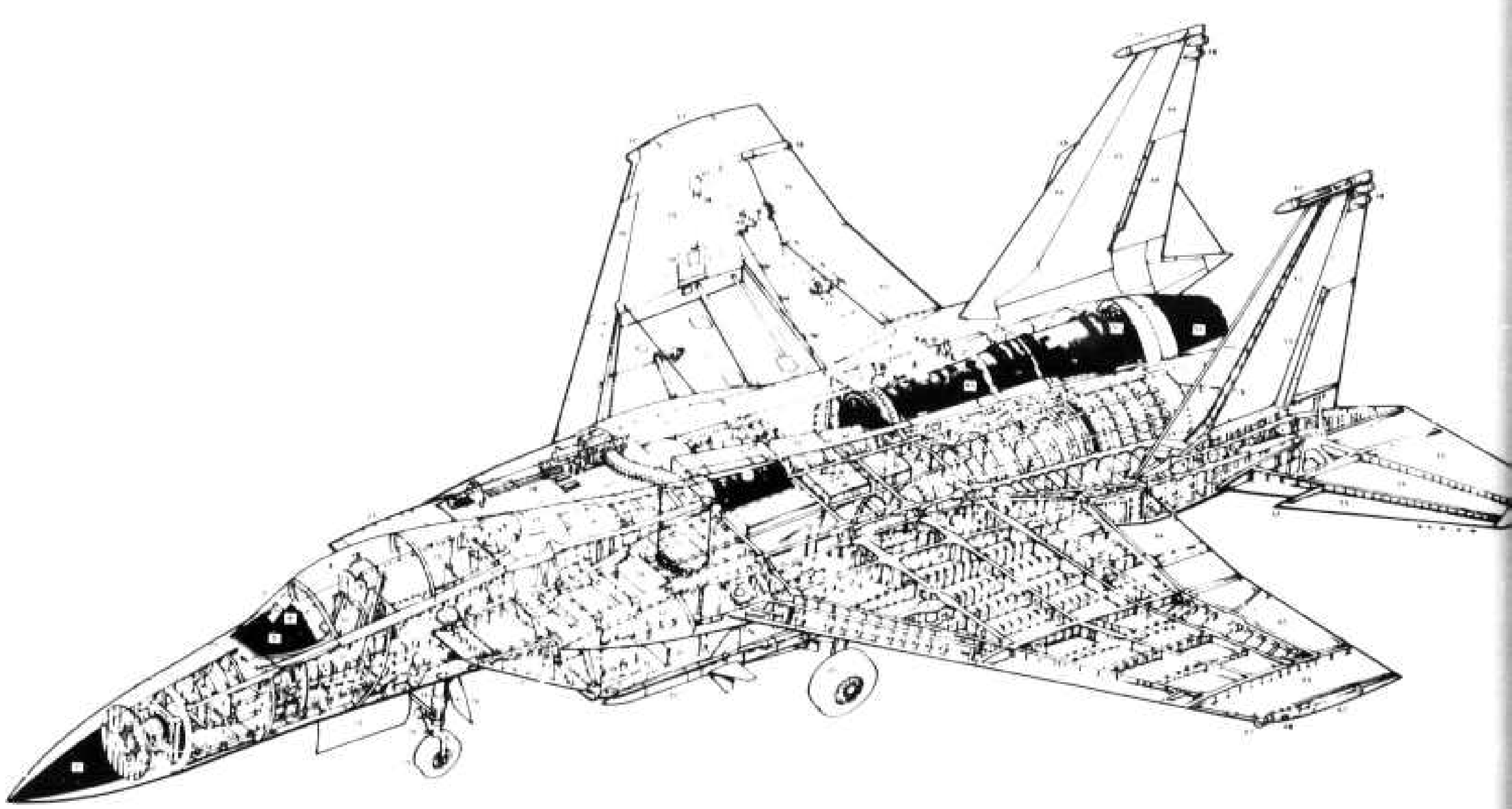
The structural arrangement of the F-4 fighter aircraft, which was introduced into the fleet about 1962, is depicted on the facing page. The production cost of the aircraft is approximately $2.8 million in then-year dollars. The structural concept is aluminum semi-monocoque.

F-4 STRUCTURAL ARRANGEMENT



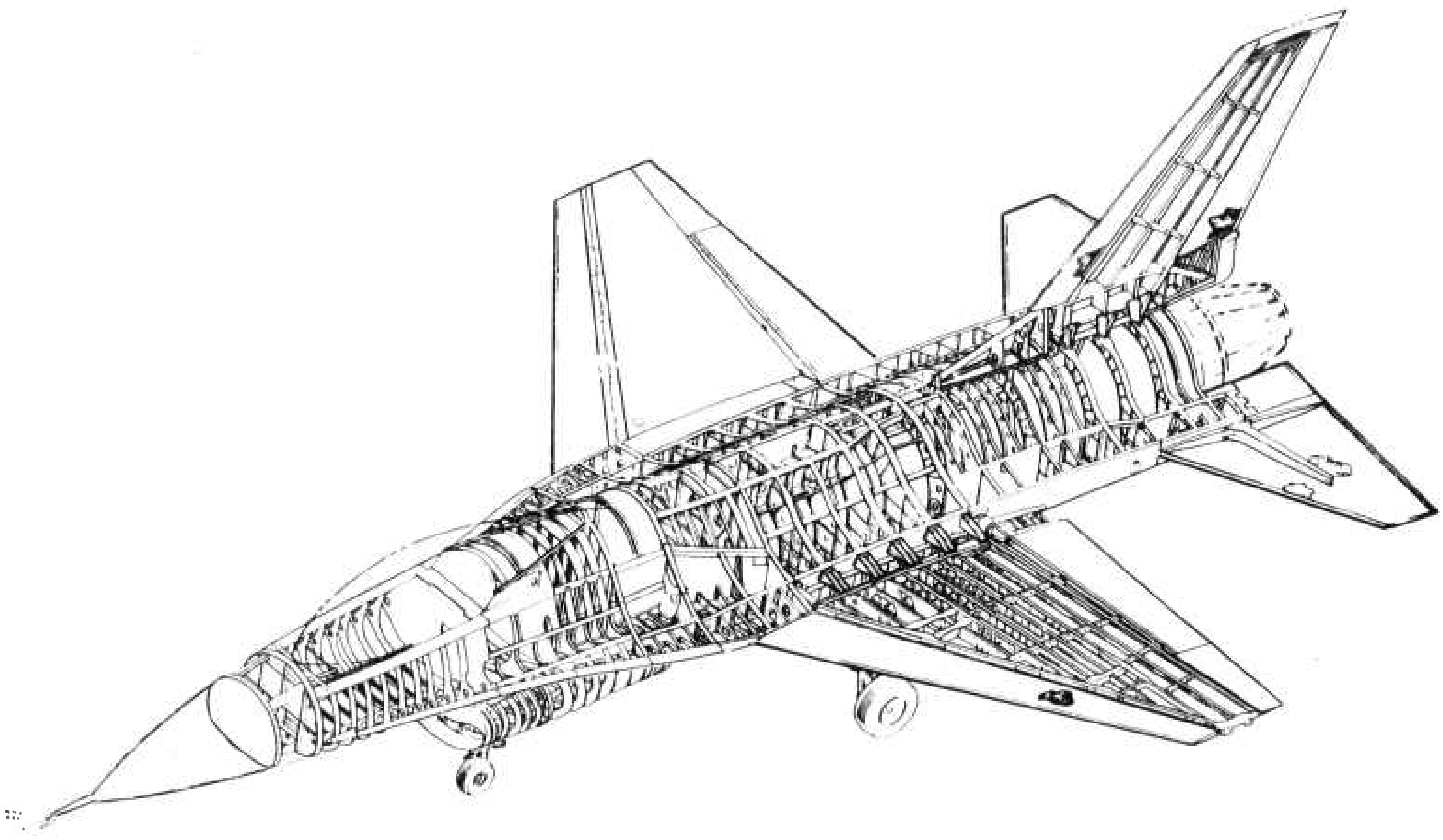
This chart illustrates the structural arrangement for the F-15 aircraft, which became operational in 1974. The cost of research, development, test, and evaluation (RDT&E) was approximately $31 million for each aircraft, and the production version costs about $16.5 million each. Except for the horizontal stabilator and vertical stabilizer, the structural concept is semi-monocoque. The vertical stabilizer and horizontal stabilator utilize an advanced composite structural concept.

F-15 STRUCTURAL ARRANGEMENT



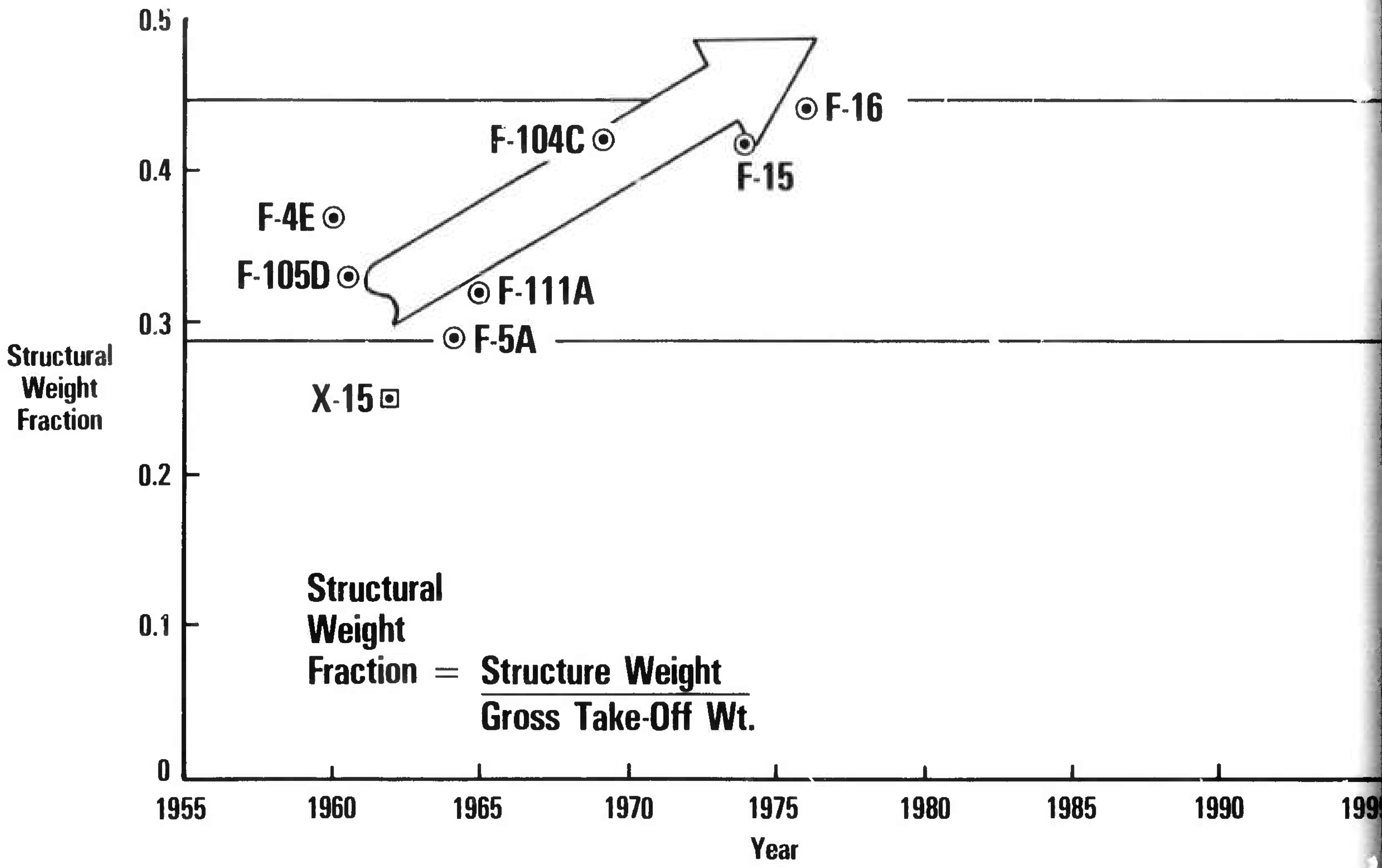
The F-16 structural arrangement is shown on the facing page. The F-16 became operational in 1979. RDT&E for this aircraft cost about $115 million each, while the production version costs approximately $15 million each. Except for the horizontal stabilizer, the structural concept is aluminum semi-monocoque.

F-16 STRUCTURAL ARRANGEMENT



The structural efficiencies of the F-4, F-15, and F-16 aircraft are illustrated on this chart. One commonly used measure of structural efficiency--the structural weight fraction--is the ratio of structure weight to the gross take-off weight of the aircraft. This chart depicts the structural fraction for a number of aircraft and the year the aircraft became operational. The trend in structural efficiency shows that the structural weight fractions of the newer aircraft are increasing instead of decreasing. The trend should be the reverse.

STRUCTURAL WEIGHT FRACTION FOR VARIOUS FLIGHT VEHICLES



Based on the trend in structural efficiency and the premise that a satisfactory return on investment (ROI) has not been made in aeronautical structures because the investment has been inadequate,[1] the Defense Advanced Research Project Agency (DARPA), in concert with the Air Force, concluded that a study on structures technology is warranted. System Planning Corporation (SPC) was tasked to perform this work.

The objective of the study, as shown on this chart, was to develop quantitative and qualitative parameters that can be utilized to judge the significance of the structures technology program. These measures of benefit (MOBs) can be used in four ways: (1) to assess the structural requirements of future weapon systems, (2) to determine the adequacy of the current structures technology program, (3) to determine deficiencies and identify new structures initiatives to eliminate these deficiencies, and (4) to assist in determining the ROI from the new initiatives.

---

[1]The Air Force has invested approximately $60-$70 million in the past 10 years on advanced metal structural concepts. When this is compared with the cost of one F-16 RDT&E aircraft (approximately $115 million), the investment appears to be minimal.

OBJECTIVE AND APPLICATION

- The objective of this study is to develop quantitative and/or qualitative parameters that can be utilized to judge the significance of aeronautical structures technology programs
- These parameters, termed Measures of Benefit (MOBs), can:
  - Assess structural aspects of future Air Force weapon systems
  - Determine adequacy of current structures technology program for future weapon systems
  - Determine deficiencies and be used to develop new structures technology initiatives
  - Assist in determining return on investment for new initiatives

The study team devoted the initial portion of its time to a literature search. The team worked first through the Defense Technical Information Center (DTIC) in Alexandria, Virginia. From the more than 35,000 DTIC key words, this chart illustrates the 26 key words that SPC selected to obtain information. The strategy of using these key words in the literature search proved to be unsatisfactory; the information derived from one key word (e.g., fatigue life) was too wide ranging, and when key words were combined, the data obtained were too limited.

DEFENSE TECHNICAL INFORMATION CENTER'S KEY WORDS

- Aerospace craft
- Aerospace planes
- Air Force budgets
- Boost glide vehicles
- Carbon-carbon composites
- Carbon-reinforced composites
- Composite structures
- Ductile brittle transition
- Dynamic loads
- Epoxy laminates
- Fatigue life
- Fatigue tests (mechanics)
- Fatigue (mechanics)
- Fiber-reinforced composites
- Fracture mechanics
- Heat shields
- Heating
- Honeycomb structures
- Hypersonic vehicles
- Infrared suppressors
- Interplanetary space
- Manned spacecraft
- Protective coatings
- Refractory coatings
- Spacecraft
- Structures

Another facility that was utilized during the literature search was the Aerospace Structures Information and Analysis Center (ASIAC). As shown on this chart, ASIAC was established in 1972 as a result of recommendations made by the Air Force Scientific Advisory Board on the structural integrity of Air Force aircraft. ASIAC acts as a focal point for the collection and dissemination of aerospace structures information for the Air Force. The facility, located at Wright-Patterson Air Force Base, Ohio, is contractor operated.

AEROSPACE STRUCTURES INFORMATION AND ANALYSIS CENTER

- ASIAC was established in 1972
- Resulted from Air Force Scientific Advisory Board recommendations on the structural integrity of Air Force aircraft
- ASIAC acts as a focal point for collection and dissemination of aerospace structures information for the Air Force
- Located in Bldg. 45, Area B, Wright-Patterson Air Force Base, Ohio
- Contractor operated – Anamet Laboratories, Inc., Berkeley, California

This chart illustrates the various services available at ASIAC. It can accomplish interactive on-line literature searches of various data bases and it houses an extensive technical library of more than 25,000 microfiche and 9,500 hardcopy reports that are available for loan. ASIAC also maintains a number of computer programs for use in solving structural problems.

AEROSPACE STRUCTURES INFORMATION AND ANALYSIS CENTER

- Interactive on-line literature searches
  - DTIC
  - Lockheed's dialog information retrieval system
  - Central Information Reference and Control (CIRC II) retrospective retrieval system
- Technical library
  - Over 25,000 microfiche
  - 9,500 hardcopy reports (available for loan)
- Computer programs

Because the ASIAC library is not computerized, the SPC study team manually reviewed more than 2,000 cards in the card file. One hundred and thirty-seven reports were selected for scrutiny to determine if they merited additional analysis; the SPC study team chose 28 reports for in-depth study.

ASIAC LITERATURE SEARCH

- ► Over 2,000 cards manually reviewed
- ► 137 reports read
- ► 28 reports studied

SPC defined two Air Force weapon systems that were used as a focal point for the development of the MOBs. The strategy that was used to define the weapon systems included conducting a literature search of documents by Boeing, NASA, McDonnell Douglas, and others and reviewing in-house studies (including a structures and materials study of lifting reentry vehicles performed for DARPA). In addition, discussions with members of the Air Force, DARPA, USDR&E, NASA, and the aerospace industry were used to help define the future weapon systems. The weapon systems described subsequently in this report represent composite vehicles that were derived by integrating the results of these activities.

DEFINITION OF FLIGHT VEHICLES – STRATEGY

- Literature
  - Documented studies
  - In-house studies
- Personal discussions
  - Air Force
  - DARPA
  - USDR&E
  - NASA
  - Aerospace industry

The operational characteristics of the Advanced Tactical Fighter are shown here. This multimission aircraft is envisioned to be the mainstay of the tactical fleet. It has short take-off and landing capability (STOL) and a turnaround refuel and reload time of approximately 1/2 hour. The launch configuration of this conceptual weapon system would be similar to a conventional Air Force aircraft, although lift enhancement devices may be necessary to achieve the STOL performance. The system life would be as currently specified in Air Force specifications and the aircraft would operate in accordance with standard Air Force military procedures.

OPERATIONAL AND TECHNICAL CHARACTERISTICS OF ADVANCED TACTICAL FIGHTER AIRCRAFT

Operational characteristics

• Launch on demand	Upon receipt of warning the aircraft should be launched in 5 minutes
• Low turnaround time	In an interceptor role, the aircraft should be refueled and reloaded in 1/2 hour
• Horizontal landing	STOL – 2000-ft field
• Crew size	1 - 2
• Launch configuration	Normal Air Force configuration; takeoff run may be shortened by lift engines or lift enhancement devices
• Aircraft operations	Normal Air Force military operations
• System life	Current Air Force specifications
• Fleet size	Mainstay of tactical fleet -- hundreds of vehicles
• Mission	Multimission. Tactical interdiction (lo-lo-hi), tactical counterair

The technical characteristics of the Advanced Tactical Fighter Aircraft, listed on the facing chart, indicate that the development of this aircraft will require significant technological advancements. The interdiction mission requires a combat radius of 900 nmi for the lo-lo-hi mission and 100 nmi at Mach 1.2 at sea level. The aircraft must possess STOL capability and also have a maximum speed of Mach 2.5-3.0 at altitude and Mach 1.2 at sea level. The payload, which is 6,000 lb, must be internal or conformal carriage. The weapons carriage must also be internal or conformal to produce a reduced radar cross-section that is one-fifth the present values for fighter aircraft of this class. The Advanced Tactical Fighter will require significant advancement in structures technology and other related aeronautical technologies.

OPERATIONAL AND TECHNICAL CHARACTERISTICS OF ADVANCED TACTICAL FIGHTER AIRCRAFT (Continued)

Technical characteristics	
• Combat radius	
– Interdiction	900 nmi total lo-lo-hi; 100 nmi at Mach 1.2 at sea level
– Counterair/air superiority	600 nmi/400 nmi
• Landing	STOL – 2000-ft field
• Maximum speed	Mach 2.5–3.0 at altitude; Mach 1.2 at sea level
• Load factor	7.33 limit
• Take-off gross weight range	35,000 to 75,000 lb
• Temperature range	Adiabatic wall temperature
• Payload	6000 lb internal or conformal
• Mission profile	Lo-lo-hi; 100 nmi at Mach 1.2 at sea level; 900 nmi total radius
• Radar signature with weapons	Reduced – 1/5 present values
• Weapon carriage	Internal or conformal

The operational characteristics of the Advanced Concepts Flight Vehicle are listed here. The vehicle is a fully reusable, launch-on-demand, lifting reentry space system that is capable of aircraft type operations. It can be launched within one hour of demand and has low turnaround time from one mission to the next. Launch will be required within the Continental United States (CONUS), thus requiring a horizontal launch or a modified vertical launch configuration. The vehicle will have a long life (by normal space standards) of 100 missions, but the fleet size will be small. It will be capable of accomplishing multiple missions--offensive, defensive, and reconnaissance.

OPERATIONAL AND TECHNICAL CHARACTERISTICS OF ADVANCED CONCEPTS FLIGHT VEHICLE

Operational Characteristics	
• Launch on demand	Launch time approximately 1 hour
• Low turnaround time	Fully reusable aircraft-type ground operations, relatively short time (hours)
• Horizontal landing	At conventional military bases or first class civil airports; approximately 150 knots landing speed; compatible with FAA Air Traffic Control System
• Launch in CONUS	Yes, in CONUS interior
• Orbital/once around	CONUS to CONUS and orbital
• Crew size	2
• Launch configuration	Either vertical or horizontal
• Aircraft operations	All ground and maintenance operations comparable to present Air Force aircraft
• System life	100 missions
• Fleet size	Small (10's)
• Mission	Multiple – offensive, defensive, reconnaissance

This chart shows the technical characteristics of the Advanced Concepts Flight Vehicle. The hypersonic lift-to-drag (L/D) ratio of 3 provides a very large lateral footprint on the order of 1,000 nmi. This L/D also produces a reentry time of about one hour with nose cap temperatures of approximately 2700°F. The low subsonic L/D, which is a characteristic of lifting reentry vehicles, produces a severe sink rate of 20-25 ft/sec. The vehicle is capable of orbital operations or CONUS-to-CONUS missions, thus providing superior operational flexibility. The maximum orbital payload is approximately 10,000 lb, and for polar orbits this payload may be reduced.

OPERATIONAL AND TECHNICAL CHARACTERISTICS OF ADVANCED CONCEPTS FLIGHT VEHICLE (Continued)

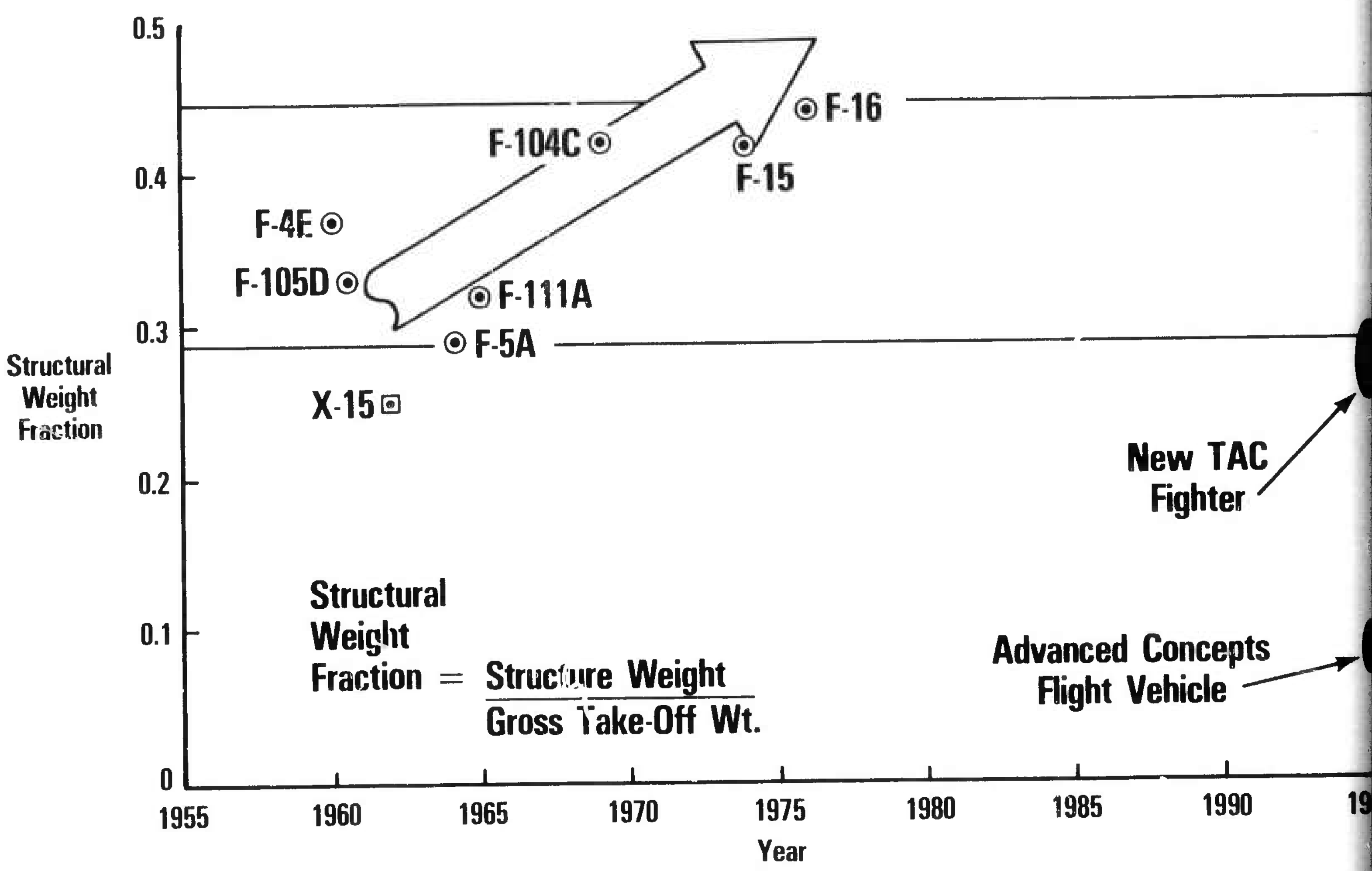
Technical Characteristics

• Hypersonic lift-to-drag	Approximately 3.0 at Mach 5.0
• Footprint (landing)	>1000 nmi lateral
• Reentry time	1 hour
• Landing speed	Conventional military aircraft capabilities – 150 knots on military and first class civil airports
• Sink rate	20-25 ft/sec
• Load factor	4-g limit
• Gross lift-off weight range	75,000-500,000 lb
• Space capability	CONUS to CONUS and orbital
• Temperature range	2700°F maximum during reentry (nose cap); surface temperature – 1500°F max
• Payload	Up to 10,000 lb; for polar orbit, payload may be reduced
• Weapon carriage	Internal

This chart illustrates what structural weight fractions are required for the conceptual Advanced Tactical Fighter and the Advanced Concepts Flight Vehicle, assuming that propulsion and aerodynamic technology has made only modest advances by 1995. Significant advancements will have to be made in the structures area to achieve the low structural fractions that are required.

This illustration can be used in two ways: It can be used to justify the requirement for new structures technology programs or it can be used to demonstrate that the F-15 and F-16 are better performing aircraft than the F-4 even though the structural weight fraction has increased--thus enabling one to conclude that the structural weight fraction is not a valid parameter by which to judge the significance of structural technology programs. The point is that since there are many parameters that can be used to measure and judge the significance of structures technology programs, it is unwise to rely on only one or two parameters.

STRUCTURAL WEIGHT FRACTION FOR VARIOUS FLIGHT VEHICLES



Some of the structural MOBs that were developed by SPC during this study are illustrated on this chart. These parameters were derived from three sources: the literature search, discussions with management/technical experts, and experiences of the study team. The categories of structures/materials and manufacturing represent the design and fabrication phases of the weapon system development. The remaining portions of the weapon system cycle--the ownership, and operational phases--are illustrated on the following chart.

Because all of the MOBs influence the final configuration of the structures, they have significant influence on the structures technology programs that must be accomplished to develop the required capabilities. Usually, a uniqueness MOB (here under structures/materials) is not a good structural parameter; it was included here to indicate whether unique structural concepts are required to meet the structural requirements. Another measure, damage repair/sustainability (under structures/materials), has been receiving increased attention in the past year from an operational viewpoint, but has received minimal attention in structural technology programs.

STRUCTURAL MOBs

Structures/Materials

- Conceptual applicability
- Uniqueness
- Availability
- Physical characteristics
- Structural ratio
- Fabrication difficulty
- Parts reduction
- Surface condition
- Weathering/corrosion
- Vulnerability
- Damage tolerance
- Damage repair/sustainability

Manufacturing

- Further technology development
- Material procurement
- Design
- Fabrication
- Tooling
- Assembly
- Quality assurance
- Testing/certification

The ownership and operational MOBs are illustrated on the facing page. Ownership is influenced primarily by various cost parameters, but the environmental measure is also important. For example, if a graphite advanced composite structure is ignited, the resulting airborne residue may have severe effects on electrical power generation facilities. This would consequently influence the ownership aspects of the weapon system.

The MOBs shown here for the operational category primarily constitute the performance parameters of the weapon system. These variables influence the structural configuration of the weapon system and the thrust of the structures technology programs that are accomplished to support such developments.

The 36 MOBs that SPC developed to judge the significance of aeronautical structures technology programs are applicable during the entire life of the weapon system, encompassing structures/materials, manufacturing, ownership, and operational categories.

STRUCTURAL MOBs
(Continued)

Ownership

- Vehicle acquisition costs
- Fleet size
- Direct costs
- Indirect costs
- Life cycle costs
- Environmental

Operational

- Speed
- Altitude
- Orbital
- Radius/payload
- Fuel consumption
- Stability and control
- Landing-takeoff requirements
- Multimission
- Reload/hold
- Size-weight

This chart illustrates a benefit/interest matrix approach for using the MOBs. The MOBs are listed on the left; a series of different technical/management expert categories is listed across the top of the table. Three codes are utilized to associate a particular MOB with an expert: (1) The expert normally is not exposed to the particular MOB, (2) the expert is exposed to the MOB, or (3) the expert is exposed to the MOB and appreciates its significance. A technical expert who is concerned with broad policy is the Commanding General of an organization or the Secretary of Defense. The technical expert would be the project engineer who is responsible for the management of the structures/materials category.

MOBs for the structures/materials category cover a broad range of interest. For example, only two of the MOBs are normally exposed to the Secretary of Defense, i.e., availability and vulnerability, whereas all of the MOBs are appreciated by the middle manager as well as by the technical expert. Therefore, through use of the benefit/interest matrix, careful selection of the MOBs enables one to tailor discussions and improve communications and understanding.

STRUCTURES/MATERIALS

MOB	1 BROAD POLICY	2 TOP MANAGER	3 MIDDLE MANAGER	4 TECHNICAL EXPERT	5 OPS PLANNER	6 OPERATOR	7 CERTIFICATION
	TECHNICAL/MANAGEMENT EXPERT						
• Conceptual applicability	–	*	*	*	X	–	*
• Uniqueness	–	–	*	*	–	–	–
• Availability	X	*	*	*	*	–	–
• Physical characteristics	–	–	*	*	–	–	–
• Structural fraction	–	X	*	*	X	–	X
• Fabrication difficulty	–	*	*	*	X	–	X
• Parts reduction	–	*	*	*	X	*	–
• Surface condition	–	–	*	*	X	*	X
• Weathering/corrosion	–	X	*	*	*	*	X
• Vulnerability (IR, laser, physical, etc.)	X	*	*	*	*	*	–
• Damage tolerance	–	*	*	*	*	*	X
• Damage repair/ sustainability	–	*	*	*	*	*	X

* Appreciates – No exposure X Exposure

The benefit/interest matrix for the manufacturing category is illustrated here. The only MOB of interest to the Secretary of Defense would be testing/certification, and he is exposed to that MOB because of concerns related to national ground/flight test facilities. The technical expert appreciates all of these MOBs, but the operator appreciates only the testing/certification MOB and only has exposure to the material procurement aspects of manufacturing.

MANUFACTURING

MOB	BROAD POLICY 1	TOP MANAGER 2	MIDDLE MANAGER 3	TECHNICAL EXPERT 4	OPS PLANNER 5	OPERATOR 6	CERTIFICATION 7
	TECHNICAL/MANAGEMENT EXPERT						
• Further technology development	–	X	*	*	X	–	X
• Material procurement	–	*	*	*	X	X	–
• Design	–	–	*	*	X	–	X
• Fabrication	–	X	X	*	X	–	*
• Tooling	–	–	*	*	–	–	X
• Assembly	–	–	*	*	–	–	
• Quality assurance	–	–	*	*	–	–	*
• Testing/certification	X	*	*	*	*	*	*

– No exposure
X Exposure
* Appreciates

Ownership is of high interest to the high-level management expert such as the Secretary of Defense. An individual at this level is exposed to or appreciates all of the ownership MOBs. As would be expected, acquisition costs, fleet size, and life cycle costs are the areas most appreciated by a broad policy expert.

Ownership is a category that is exposed to most of the technical/management experts and most of the MOBs are also appreciated by these various experts. It is apparent that ownership is a high visibility category that has almost universal interest throughout the technical/management structures technology community.

OWNERSHIP

TECHNICAL/MANAGEMENT EXPER

MOB	BROAD POLICY 1	TOP MANAGER 2	MIDDLE MANAGER 3	TECHNICAL EXPERT 4	OPS PLANNER 5	OPERATOR 6
• Vehicle acquisition costs	*	*	*	*	*	X
• Fleet size	*	*	*	*	*	*
• Direct costs	X	X	X	*	*	*
• Indirect cost	X	X	X	*	*	*
• Life cycle costs	*	*	*	*	*	—
• Environmental (pollution toxicity)	X	*	*	*	*	*

-- No exposure
X Exposure
* Appreciates

The benefit/interest matrix for the operational category is illustrated on this chart. The trends are similar to the matrix for the ownership category. The MOBs are appreciated by a very large segment of the technical/management community and there are very few MOBs that are not exposed to this broad range of experts. Of interest is that the fuel consumption MOB is universally appreciated.

As is evident from all of the benefit/interest matrices, the MOBs appeal to a large segment of the experts associated with aeronautical structures technology. The ownership category is appreciated by a larger segment of the experts then are the materials/structures, manufacturing, and operational categories.

OPERATIONAL

MOB	BROAD POLICY 1	TOP MANAGER 2	MIDDLE MANAGER 3	TECHNICAL EXPERT 4	OPS PLANNER 5	OPERATOR 6	CERTIFICATION 7
	TECHNICAL/MANAGEMENT EXPERT						
• Speed	X	*	*	*	*	*	*
• Altitude	—	X	*	*	*	—	*
• Orbital	X	*	*	*	*	—	X
• Radius/payload	X	*	*	*	*	*	*
• Fuel consumption	*	*	*	*	*	*	*
• Stability and control	—	X	*	*	—	*	*
• Landing-takeoff requirements	—	X	*	*	*	*	*
• Multimission	X	*	*	*	*	*	—
• Reload-hold	X	*	*	*	*	*	—
• Size-weight	X	*	*	*	*	*	*

— No exposure
X Exposure
* Appreciates

The MOBs also can be used to determine technology deficiencies, as illustrated on the facing page. The MOBs are listed in the first column and units are assigned to the applicable MOBs, as shown in the second column. By reviewing the Air Force's current structures technology program, it is possible to determine what level can be expected for each MOB from the program. The results of this analysis are documented in Column 3. The next two columns show what level is required to satisfactorily develop the new Advanced Tactical Fighter (referred to here as "new TAC Fighter") and the Advanced Concepts Flight Vehicle. The difference between Columns 3 and 4 and 3 and 5 are tabulated in Columns 6 and 7, respectively. These last two columns show the technological deficiencies for the Advanced Tactical Fighter and the Advanced Concepts Flight Vehicle if no change is made to the existing Air Force structures technology program.

Unique, new structural concepts are required for the Advanced Tactical Fighter; the current technology program is only marginally adequate to address improved physical characteristics of structural materials.

For the Advanced Concepts Flight Vehicle, the deficiencies include a lack of new structural concepts and high temperature structure effort. There is also a significant deficiency associated with the structural fraction. Current technology will produce a structural fraction of 0.25-0.30 whereas the Advanced Concepts Flight Vehicle requires a structural fraction of 0.07 to 0.10. The current program is also only marginally adequate in the area of improved material physical characteristics.

STRUCTURES/MATERIALS

MOB	Units	Expected Level From Current Structures Technology Program	Level Required for New TAC Fighter	Level Required for Advanced Concepts Flight Vehicle	Deficiencies: TAC Fighter	Deficiencies: Advan[ced] Conce[pts] Flig[ht] Vehi[cle]
CONCEPTUAL APPLICABILITY	None	Provides new approaches for structural materials and concepts, i.e., cast concepts	New concept	New concept	Lacks new concepts	Lacks ne[w] concepts
UNIQUENESS	None	Provides unique possibilities such as powdered AL, T1, RAM/RAS, etc.	Application of uniqueness essential	Application of uniqueness essential	Limited	Lack of [illegible] temp str[illegible] effort
AVAILABILITY	lb/yr	See Persh study*	Order of 2×10^6 lb/yr composites	Small	Persh study*	None
PHYSICAL CHARACTERISTICS	lb, lb/in^2, lb/in^3	10-20% improvement from today's materials	10-20% absolute minimum (see NASA study)**	10-20% absolute minimum	Program marginal	Program marginal
STRUCTURAL FRACTION	None-dimensional	0.25-0.30	0.25-0.30	0.07-0.10	Small	Large
FABRICATION DIFFICULTY	Man-hours/ shop time	Unknown – receiving low attention from current program	Unknown – design dependent	Unknown – design dependent	Unknown	Unknown

*Persh study, reference Dr. DeLauer's USDR&E memorandum dated 24 Feb 1982, subject: *Composite Materials.*

**NASA study in progress by Boeing and Mcair, *Study of Potential for Sustained Supersonic Cruise Military Aircraft Utilizing Advanced Technologies.*

For the new TAC Fighter, deficiencies exist for the MOBs of surface condition, weathering/corrosion, and damage repair/sustainability. For the Advanced Concepts Flight Vehicle, the only deficiency that exists is in the damage tolerance MOB.

The parts reduction MOB has not received adequate attention in the recent past. Unfortunately, parts reduction is very sensitive to the particular component involved and the detailed design of that component. Therefore, for the new TAC Fighter, the deficiencies in this area are unknown. For the Advanced Concepts Flight Vehicle, the importance of this MOB is negligible because only a small number of these vehicles will be built and deployed.

STRUCTURES/MATERIALS

MOB	Units	Expected Level From Current Structures Technology Program	Level Required for New TAC Fighter	Level Required for Advanced Concepts Flight Vehicle	Deficiencies	
					TAC Fighter	Advanced Concepts Flight Vehicle
PARTS REDUCTION	Count	Comparison of Metal Versus Advanced Composite Material Forward Swept Wing Characteristics Variable — Metal Wing — Advanced Composite Wing Wing cover wt (lb) — 572 — 180 Number of fasteners — 24,178 — 14,200 Number of ribs — 22 — 16 Cost reduction (% of metal wing cost) — 0 — 16 Design dynamic pressure (lb/ft^2) — 2,058 — 2,500	Dependent on components involved	Dependent on components involved	Unknown	Negligible
SURFACE CONDITION	Roughness (micro-inches)	Not being addressed	Surface condition important	Relatively unimportant	Requires attention	Negligible
WEATHERING/CORROSION	Inches/unit time	Not being addressed from structural viewpoint	Weathering/corrosion important	Relatively unimportant	Requires attention	Negligible
VULNERABILITY	Vulnerable area in sq ft	A_v = 50 – 100 ft^2, 23 mm threat	A_v = 50 - 100 ft^2; design is primarily performance driven	Relatively unimportant	Vulnerability performance tradeoff	Negligible
DAMAGE TOLERANCE	Critical crack length in inches	Current specifications address damage tolerance	High	Critical	Minimum	Requires attention
DAMAGE REPAIR/ SUSTAINABILITY	Man-hr/shop time, depot/flt line, sorties/day, a/c available/day	Negligible Advance Threat (mm) — mm hr/Hit/Airframe 7.62 — 7.7 12.7 — 11. 14.5 — 14. 23.0 — 28.	60-80% of fleet will be grounded awaiting repairs. Goal should be less than 25% based on 1973 Middle East war	Relatively unimportant	Critical – requires attention	Negligible

The deficiencies for the manufacturing category are illustrated on this figure. (The MOBs of design, fabrication, tooling, and assembly are not within the scope of this study and, therefore, were not analyzed.) These MOBs are in the Air Force manufacturing technology program (Materials Laboratory, Wright-Patterson Air Force Base, Ohio), which is administered and supported by the materials community.

For both the Advanced Tactical Fighter and the Advanced Concepts Flight Vehicle, there are serious deficiencies in the testing/certification MOB. There is a lack of environmental facilities for certifying advanced composite structures, and existing facilities for simulating reentry heating (for the Advanced Concepts Flight Vehicle) need to be modernized. There are also critical deficiencies in the area of procurement specifications and design criteria specifications for the Advanced Concepts Flight Vehicle. Both weapon systems require further technology development if satisfactory structural manufacturing capabilities are to be available when required.

MANUFACTURING

MOB	Units	Expected Level From Current Structures Technology Program	Level Required for New TAC Fighter	Level Required for Advanced Concepts Flight Vehicle	Deficiencies	
					TAC Fighter	Ad Co I V
FURTHER TECH DEV	Δ%	Marginal	Requires detail design	Requires detail design	Requires attention	Re at
MATERIAL PROCUREMENT	$/lb	Persh report	Requires detail design	Requires detail design	Minimum	No pr specif
DESIGN FABRICATION TOOLING ASSEMBLY	hr/lb hr/lb hr/lb hr/lb	Not in scope of present study; primarily manufacturing technology program				
QUALITY ASSURANCE	hr/lb	Marginal	High – requires detail design	ıigh – requires detail design	Critical – inspection technique	Critica no sp
TESTING/CERTIFICATION	hr, $	Adequate for conventional a/c Inade..ıate for space-related craft	Inadequate for composites	Critical – requires immediate attention	Critical – lack of environmental facilities	Critic lack facili test

Only limited deficiencies have been identified for the ownership category. Ownership MOBs of future weapon systems are dependent on a number of variables that can only be defined during the preliminary design. For example, the fleet size MOB depends on the threat and scenario for the time period under consideration. The scenario also influences the life cycle cost MOB, and the rate of inflation has a direct influence on the vehicles' acquisition cost. Therefore, ownership deficiencies for both the new TAC Fighter and the Advanced Concepts Flight Vehicle are unknown. As the system development proceeds, these deficiencies will become more evident.

OWNERSHIP

MOB	Units	Expected Level From Current Structures Technology Program	Level Required for New TAC Fighter	Level Required for Advanced Concepts Flight Vehicle	Deficiencie	
					TAC Fighter	Ad Co F V
VEHICLE ACQUISITION COSTS	$/lb	$2000/lb range for conventional A/C $3000/lb range for space vehicles	Unpredictable due to inflation	Unpredictable due to inflation	Unknown	Un
FLEET SIZE	Numerical	Studies indicate 10% reduction due to adv. tech. on mission effectiveness	Scenario and design dependent 100's of aircraft	Scenario dependent 10's of vehicles	Unknown	Un
DIRECT COSTS	$	5-10% reduction	Not defined	Not defined	Unknown	Un
INDIRECT COSTS	$	5-10% reduction	Not defined	Not defined	Unknown	Un
LIFE CYCLE COSTS	$	6% reduction for 10-yr life	Mission and scenario dependent	Mission and scenario dependent	Unknown	Un
ENVIRONMENTAL	Varies, i.e., DB, NOX, etc.	Partially addressed	Low priority	Low priority	Minimum	Mi

The operational category is shown on this chart. Many deficiencies exist for the Advanced Concepts Flight Vehicle: Only 2 of the 10 operational MOBs (fuel consumption and stability and control) do not have critical deficiencies. This situation is a direct result of the low priority given to structures technology programs that address lifting reentry flight vehicles.

The radius/payload requirements of the new TAC Fighter greatly exceed what the current technology program is capable of producing. This critical deficiency could jeopardize the development of this weapon system. Another critical deficiency, the size-weight MOB, could have a significant influence on the final configuration of the Advanced Tactical Fighter.

OPERATIONAL

MOB	Units	Expected Level From Current Structures Technology Program	Level Required for New TAC Fighter	Level Required for Advanced Concepts Flight Vehicle	Deficiencies	
					TAC Fighter	Advanced Concepts Flight Vehicle
SPEED	Mach	2.5-3.0 Mach No orbital program	2.5-3.0 Mach	Orbital	Negligible	Critical
ALTITUDE	ft, nmi	0-80,000 ft No orbital program	0-80,000 ft	Orbital	Negligible	Critical
ORBITAL		No program		Orbital		Critical
RADIUS/PAYLOAO	nmi/lb	500 nmi/5500 lb	900 nmi/6000 lb	Polar orbit/10,000 lb	Critical, requires attention	Critical
FUEI CONSUMPTION	lb/sec	Design dependent; approx. 25% reduction possible	Critical	Not applicable	Requires attention	Not applicable
STABILITY AND CONTROL		Increases design options	Not critical	Not critical	Negligibie	Negligible
LANOING ANO TAKEOFF	ft	STOL-conventional a/c No program for space vehicle	2000 ft	Takeoff CONUS base, land commercial airport	Modest	Critical
MULTIMISSION		Current spec on system life No orbital program	Current specification on system life	100 mission (multimission)	Modest	Critical
RELOAO-HOLO	hr	Launch 5 min, reload 30 min No program for space vehicles	Launch 5 min, reload 30 min	Launch 1 hr, reload min, hr	Minimum	Critical
SIZE – WEIGHT	ft-lb	Oesign dependent, 15-20% reduction in weight No program for space vehicles	35,000-75,000 lb	75,000-500,000 lb	Critical	Critical

The remaining portion of this report addresses new structures initiatives to overcome the identified technology deficiencies. The SPC study team reviewed all the identified deficiencies and structured a technology program that considers all of the important points.

For the Advanced Tactical Fighter, the first part of the technology program should be a trade study that considers all of the MOBs illustrated on the facing chart. These parameters are interconnected and influence the structural and material aspects of the aircraft. It appears that some performance tradeoffs will be necessary if an Advanced Tactical Fighter that meets the majority of the desired requirements is to be realized. The trade study should define an aircraft configuration and then determine what structural approaches are necessary to meet the required MOBs. This study will also have to indicate the cost tradeoffs that are possible as a function of the desired performance parameters. These cost tradeoffs are expected to show that certain MOBs, such as radius/payload, drive the cost situation and that it is not economical to attempt to achieve the performance requirements of these MOBs.

NEW STRUCTURES INITIATIVE
ADVANCED TACTICAL FIGHTER

► Trade study to define aircraft parameters and configuration with emphasis on material and structural aspects:

- Radius/payload
- Fuel consumption
- Landing/take-off performance
- Multimission capability
- Size/weight
- Acquisition costs
- Fleet size
- Direct costs
- Indirect costs
- Life cycle costs

Once the trade study has been completed, the structures initiative should be directed toward the development of new structural concepts. This activity, as summarized on the facing chart, should consider concepts that normally are not utilized in conventional type aeronautical structures. Advanced composite structures that have unique physical characteristics such as tailored stiffness with good radar absorbing materials (RAM) should be investigated. Other factors that should be considered include battle damage repair/sustainability, fabrication difficulty, and design-to-part-count criteria. Advanced design/analysis techniques will also have to be developed because the unique structural concepts that evolve from this activity cannot be analyzed conventionally. Advanced ground and flight test techniques will have to be developed because of the unique structural concepts that are involved. The availability of materials also will have to be considered during the development of the new structural concepts.

NEW STRUCTURES INITIATIVE
ADVANCED TACTICAL FIGHTER
(Continued)

► Develop new structural concepts that consider:
- Uniqueness
  - Cast, metal matrix, advanced composites, etc.
  - Physical characteristics (i.e., RAM, stiffness, surface condition, weathering/corrosion)
  - Battle damage repair, sustainability, maintainability, reliability
  - Fabrication difficulty
  - Parts reduction
  - Quality assurance inspection techniques
- Advanced design/analysis methodology
- Advanced test requirement (ground/flight)
  - Static
  - Fatigue
  - Weathering/corrosion
  - Environmental
  - Certification
- Availability of materials

This chart lists the technical areas that will not require major effort. Current technology programs that are devoted to the nonnuclear vulnerability/survivability of aircraft from conventional weapons will provide the technology required for the Advanced Tactical Fighter. Therefore, minimum effort will be required in the vulnerability area. Current Air Force specifications on structural durability will provide the damage tolerance factors required for design; thus, no significant effort will be required in this important area. Since the Advanced Tactical Fighter will use conventional materials that are available from the industry, no new material procurement specifications will be required for the aircraft development.

The design, fabrication, tooling, and assembly MOBs are of great interest in regard to the Advanced Tactical Fighter, but these areas were not addressed because they are not within the scope of the study.

NEW STRUCTURES INITIATIVE
ADVANCED TACTICAL FIGHTER
(Continued)

- ► Areas not requiring major effort:
  - Vulnerability
  - Damage tolerance factors
  - Material procurement
- ► Items of interest but not presently addressed:
  - Design
  - Fabrication
  - Tooling
  - Assembly

The initial effort in the new structures initiative for the Advanced Concepts Flight Vehicle should be a trade study to determine the configuration of the vehicle. The MOBs that should be considered during this study are shown here. The life cycle cost MOB is strongly influenced by the thermal protection system (TPS) that is utilized. If the TPS is a refurbishable arrangement, then overall life cycle costs may be increased because the TPS must be renewed after each mission. If the TPS is passive (i.e., requires no refurbishment after a mission), then the life cycle costs may be reduced. The trade study will determine the advantages and disadvantages of each approach and also the influence of the other MOBs on the material and structural concepts that are required.

NEW STRUCTURES INITIATIVE

ADVANCED CONCEPTS FLIGHT VEHICLE

► Trade studies to define vehicle parameters and configuration with emphasis on material and structural aspects:

- Orbital speed
- Orbital altitude
- Radius/payload
- Landing/take-off performance
- Multimission capability
- Reload-hold variations
- Size/weight
- Vehicle acquisition cost
- Direct cost
- Indirect cost
- Life cycle cost
  - Refurbishable mode
  - Passive mode

Two structural philosophies for lifting reentry flight vehicles have persisted over the past 25 years. One approach, which permits the structure to heat up, is called the "hot structure." The other approach, called "cold structure," does not allow the structure to heat up. Past programs have utilized both of these concepts and, unfortunately, the results of these programs do not indicate which concept is the most satisfactory. Therefore, a primary consideration in the Advanced Concepts Flight Vehicle structures initiative should be the experimental verification of both of these concepts to establish the required structures and materials data base. This verification should involve five phases--design, fabrication, ground test, technology transfer, and documentation. It is recommended that DARPA sponsor this effort, with strong Air Force participation, in a competitive environment within the aerospace industry. The structural concepts will have to be unique and will probably utilize advanced structures such as carbon-carbon composites. Fabrication difficulty and quality assurance inspection techniques will also be very important MOBs during the development of the Advanced Concepts Flight Vehicle.

NEW STRUCTURES INITIATIVE

ADVANCED CONCEPTS FLIGHT VEHICLE
(Continued)

- ► Develop new structural concepts that consider:
  - Experimental verification of structural concepts to establish the required data base; program involves five phases – design, fabrication, ground test, technology transfer, and documentation. Two structural concepts (i.e., hot structure and cold structure) should be developed in a competitive environment within the aerospace industry. Program could be a joint DARPA/Air Force initiative with DARPA assuming program advocacy and leadership. Ground test accomplished in Air Force structures test facility
  - Uniqueness
    - Cast, metal matrix, advanced composites, carbon-carbon composites, etc.
    - Physical characteristics (i.e., RAM, stiffness)
    - Sustainability, maintainability, reliability
    - Fabrication difficulty
    - Quality assurance inspection techniques

The new structural concepts that will be developed will require advanced design/analysis methodologies and procedures. The Advanced Concepts Flight Vehicle will be subjected to severe combinations of thermal and aerodynamic loads, thus requiring an extensive design analysis effort. The testing of a full-scale Advanced Concepts Flight Vehicle on the ground as well as in flight will require significant advances in structural testing technology. The new structural concepts will also involve the use of materials that currently have limited availability; therefore, the acquisition of these materials in sufficient quantities must be explored in detail.

NEW STRUCTURES INITIATIVE

ADVANCED CONCEPTS FLIGHT VEHICLE (Continued)

- Advanced design/analysis methodology
- Advance test requirements (ground/flight)
  - Static
  - Fatigue
  - Environmental
  - Test criteria
  - Modern facilities
  - Certification
- Availability of materials

Because there has been minimal attention on the development of lifting reentry flight vehicles over the past several decades, a serious void exists in the military specifications for the development of these types of vehicles. Nor do damage tolerance factors exist for lifting reentry flight vehicles. Therefore, a major effort must be directed toward the development of such data.

Current structures technology programs will provide sufficient data to permit the development of an Advanced Concepts Flight Vehicle that will have low vulnerability. Material procurement specifications are also adequate. Therefore, no major effort will be required for the vulnerability and material procurement MOBs for this vehicle.

Other MOBs of interest include design, fabrication, tooling, and assembly.

NEW STRUCTURES INITIATIVE

ADVANCED CONCEPTS FLIGHT VEHICLE (Continued)

- Major effort directed to:
  - Damage tolerance factors
  - Establish military specifications
- Areas not requiring major effort:
  - Vulnerability
  - Material procurement
- Items of interest but not presently addressed:
  - Design
  - Fabrication
  - Tooling
  - Assembly

As depicted on the facing chart, this Aeronautical Structures Technology Study has developed 36 quantitative and qualitative MOBs that cover a wide range of interest to managers and technical experts. Through careful selection of pertinent MOBs, enhanced communications and understanding of structures technology programs can ensue.

This study confirms that the MOBs have significant potential for (1) assessing the significance of aeronautical structures technology programs (2) assessing the structural requirements of future weapons systems, (3) determining the adequacy of current structures technology programs, and (4) determining deficiencies and new structures technology initiatives that may be accomplished to overcome the deficiencies.

CONCLUSIONS

- The quantitative and qualitative MOBs developed in this study cover a wide range of interests related to aeronautical structures technology
  - Different MOBs are of interest to different managers and technical experts
  - Careful selection of MOBs can be used to tailor discussions, thus enhancing communication and understanding
- The MOBs appear to have significant potential for:
  - Assessing the significance of aeronautical structures technology programs
  - Assessing the structural requirements of future weapon systems
  - Determining the adequacy of current structures technology programs
  - Determining deficiencies and required new structures technology initiatives

Although the observations noted on the facing chart are not directly related to the objectives of this study, they constitute significant points that emerged during the course of SPC's work:

- The Advanced Tactical Fighter and the Advanced Concepts Flight Vehicle are two conceptual Air Force weapons systems that will provide payoffs and satisfy the requirement for significant advances in aeronautical structures technology. Both of these weapon systems must meet severe structural technology requirements that necessitate time-critical structural initiatives that are not yet in the planning stages.
- Serious deficiencies in the Air Force's current structures technology program will prevent meeting the technology needs of the projected aircraft. It is essential that new structures technology programs be undertaken now so that the technology required for these systems can be developed.
- The ASIAC facility, although an outstanding, comprehensive source to this study, requires some improvements if its full value is to be realized. The ASIAC card files should be computerized, and it also would be helpful if reports were categorized by results in addition to abstract data. The physical facilities require improvements, and a program of enhanced communication between ASIAC personnel and the customer should be fostered.
- The DTIC, which utilizes a key word procedure for literature searches, proved to be unsatisfactory for this type of study.

RELATED OBSERVATIONS

- ► At least two new weapon systems are on the horizon for the U.S. Air Force. Both of these weapon systems
  - Produce severe structural technology requirements
  - Will provide high payoff
  - Require time-critical new structural initiatives that do not exist today even in the planning stages
- ► Serious deficiencies exist in the Air Force's current structures technology program. These will prevent meeting the technology needs of the projected aircraft. New technology programs should be undertaken
- ► ASIAC is a valuable asset but its full potential is not being realized
  - Card files should be computerized
  - Physical facilities need improvement – more office space
  - Better procedures should be implemented to communicate ASIAC's capabilities to the customer
  - Excessive time consumed in establishing a manual search strategy for card files. Valuable assistance could be provided by ASIAC personnel in planning card search strategy
  - Information is not categorized by results (i.e., measures of benefit)
- ► DTIC, which utilizes a key word procedure, was difficult to use for this study. Results of search are very sensitive to the search strategy pursued

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